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OPERATING EXPERIENCE WITH A HIGH CURRENT Cs^{+1} INJECTOR FOR HEAVY ION FUSION*

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SUMMARY

The construction and assembly of a Cs ion injector consisting of a pulsed source and 3 pulsed drift tubes has been complete since April, 1980. The measurement program, underway since then to characterize the beam, has been interspersed with the development of diagnostic equipment. The Cs contact ionization source and each of the 3 drift tubes are driven by 500 kV Marx generators. The injector has been operated reliably at 300 kV/stage at a repetition rate of 1 pulse/4 sec. About 10^5 pulses have been accumulated.

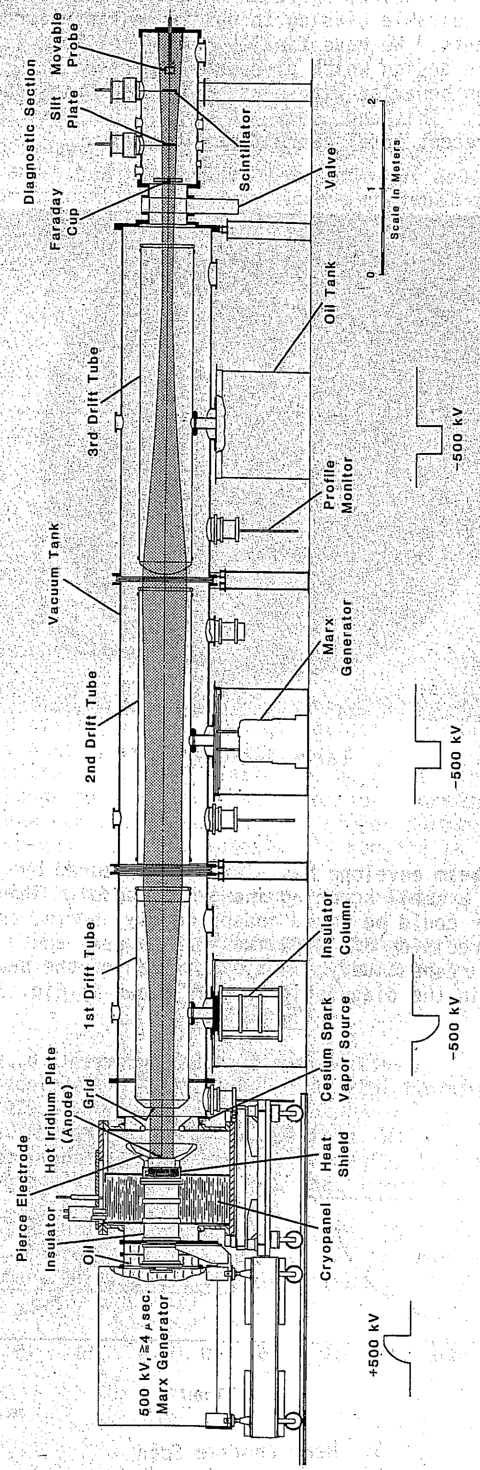
The space charge limited diode and drift tube acceleration system were designed with the aid of the EGUN code of Herrmannsfeldt[1]. Measurements of the beam envelope have been made by means of a movable biased charge collector. Good agreement with the EGUN calculation is found. Measurements of the beam emittance have been made at the exit of the third drift tube. The normalized emittance $\pi \epsilon_N = 2 \times 10^{-6}$ π m-rad is of better optical quality than that required for further acceleration and transport in a Heavy Ion Fusion (HIF) Induction Linac Driver.

INTRODUCTION

At the 1979 Particle Accelerator Conference we reported on the operating characteristics of the Cs source for our injector.[2] In this paper we report on the complete assembly and operating characteristics of the three pulsed drift tubes which are used for acceleration of the beam from the source. The system is shown schematically in Fig. 1 along with the calculated and measured beam envelope profiles.

The system has been in routine operation at 300 kV/stage, giving a beam of 1.2 MeV Cs^+ with a total current of 355 mA in a 2.6μs pulse, which is the expected space charge limited current at that voltage and with the present grid structure. In an electrostatically focussed system at the space charge limit there is only one solution to the beam dynamics, with the exception of source temperature effects which are insignificant here, and therefore the beam envelope and particle trajectory may be measured at any voltage.

The main effort over the past year has been to develop reliable diagnostics to measure the beam envelope, total current, and emittance. In



1. 3 Drift Tube Injector schematic showing beam profiles.

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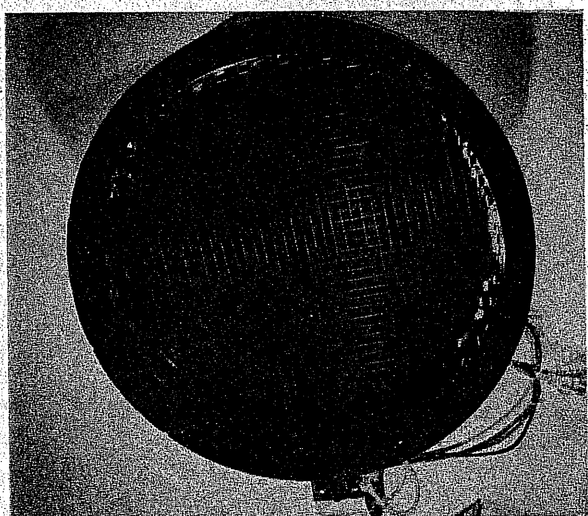
addition, tests have shown that the goal of 500 kV/stage is achievable. Finally, some of the future experiments for this injector will be described. Each of these items will be discussed in detail in the following sections.

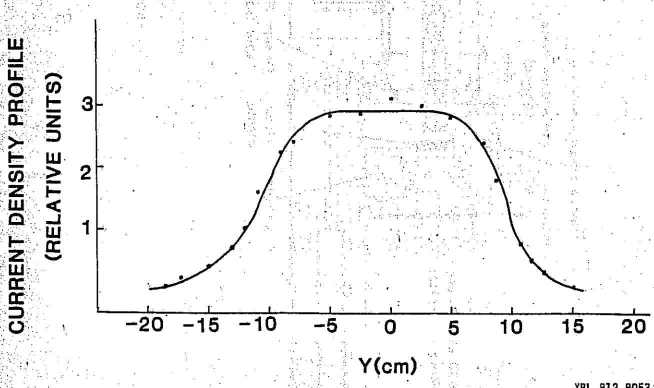
Diagnostics Development

We have invested a major share of our effort in developing reliable means of characterizing these intense, low energy ion beams. The problem of measuring total beam current has been more difficult than expected because of the high surface heating due to the short range of the ions. This leads to the evolution of an energetic plasma from the charge collector and nearby surfaces which requires a deep cup with suitable biasing to obtain reliable current measurements. We have finally arrived at an acceptable design which gives the expected saturation behavior with bias of its two grids and collector. This cup, shown in Fig. 2, has been used for all recent total current measurements.



2. Large Faraday Cup

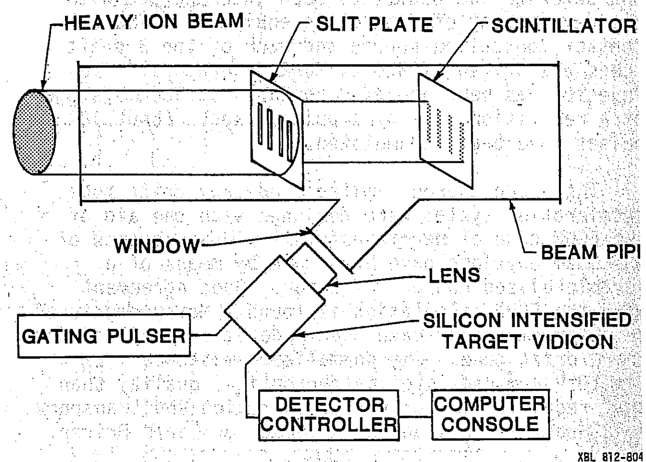
The beam envelope has also been measured by means of a small scanning charge collector. This collector could be moved independently in r,θ, and z with a precision of ±0.06 mm, ±0.1 degrees and ± 0.8 mm respectively. A typical scan of the beam profile in the diagnostic tank is shown in Fig. 3.



3. Beam Profile Scan

In addition, we have measured the beam emittance in each transverse phase plane using a plate with fine slits to reduce the spreading effect of space charge. The beam divergence was measured by both a small flag probe and a fast scintillator and camera, in order to achieve time resolution within the particle bunch.

Fig. 4 shows the arrangement of these elements in the diagnostic tank. The scintillator used recently has been a 1 μm thick layer of CaF_2 doped with europium, vacuum-evaporated onto a stainless steel plate. The scintillator is required to have a fast fluorescence decay time (~ 300 ns or faster), good efficiency of light production; and a usable lifetime in the intense beam (~1mA/cm^2). For example, Pilot B survives only 50 pulses under these conditions. KBr, which has been used previously[3], has a slower fluorescence decay time and a lower light yield than the Ca F_2 (Eu). The Ca F_2 (Eu) scintillator was viewed with an EG and G Optical Multichannel Analyzer (OMA) with a lens mounted on it. This system functions as a gateable (gating width as narrow as 40 ns), high sensitivity

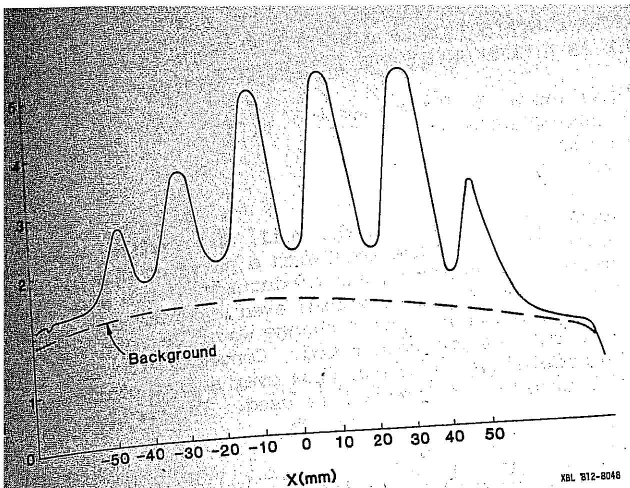


4. OMA Schematic

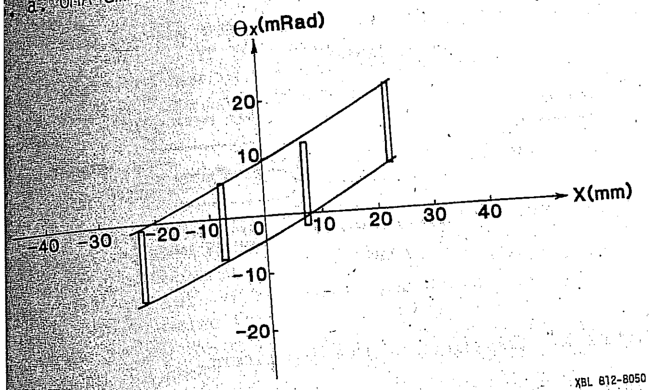
television camera. A typical light intensity pattern for 1 mm slits 15 mm apart, 62 cm from the scintillator obtained with this device is shown in Fig. 5., along with the calculated normalized emittance. The scintillator can be replaced by the movable charge collector and the pattern acquired more laboriously, point by point; an example of such data is shown in Fig. 6a. The calculated normalized emittance given by these data is displayed in Fig. 6b. It should also be pointed out that these latter measurements required a high level of machine stability and reproducibility over ~10^3 pulses.

Note that Fig. 5 represents a beam scan in the X-direction and Fig. 6 is a scan in the Y-direction, and thus results for both transverse phase planes are shown. The emittance is the same in both directions and the area $\pi\ \epsilon_N \sim 2 \times 10^{-6}\pi$ m-radians is of higher quality than that required for a heavy ion injector for an HIF Induction Linac for ICF purposes.

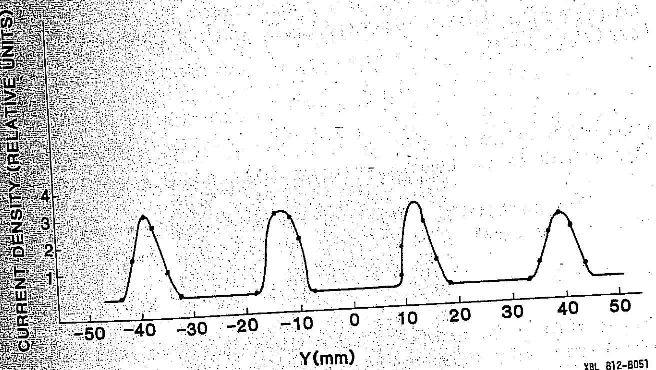
We have added a 16" gate valve between the injector and the diagnostic tank. This permits changes inside the diagnostic tank that require opening the tank to air to be made rapidly (~ 1 hour turnaround time), e.g., this has allowed use of such techniques as a cellulose nitrate film to image the ion beam. This film must be removed after each pulse and then etched for examination .



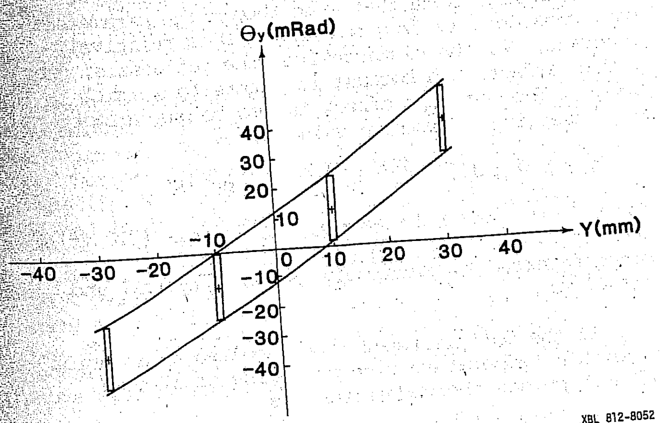
a. OMA emittance pattern



5. b. Phase space plot



6. a. Charge collector emittance pattern



6. b. Phase space plot

Suppression of Current Transients in the Source Diode

Because the single particle transit time through the source diode is a significant fraction of the pulse duration, we expected and saw substantial current fluctuations associated with the initiation of the current pulse. We have analyzed the effect for planar geometry and have found that current overshoot and oscillation at the leading edge of the current pulse can be suppressed by arranging for a programmed shape of the voltage pulse[4]. Approximate fitting of the real voltage shape by means of resistors to slow the voltage risetime gave a near-total suppression of the fluctuations about the space-charge limit.

High Voltage Testing

During the course of the assembly, one drift tube housing and insulator stack were set up and instrumented to determine their maximum voltage capability. The system was subjected to an argon gas glow discharge at ~ 0.1 torr of approximately 300 volts and 1.5 A with a continuous flow of argon. Monitoring partial pressures with a residual gas analyzer, we were able to effect an order of magnitude reduction overnight in the H_2O peak in the mass spectrum. Upon subsequent pumpdown and voltage-conditioning these insulator columns held 600 kV for > 20 μs.

Future Plans

Now that the injector is completely assembled and running we plan to use it for the following tasks:

1. Measure gas desorption by heavy ion beam impact on surfaces at normal and glancing incidence.
2. Reduce cesium consumption by optimizing the cesium vapor spark source.
3. Develop reliable calibrated beam current detectors.
4. Develop rugged transparent scintillators: [e.g. sapphire, calcium fluoride coating (doped with Eu)].
5. Perfect emittance measurement with slits, scintillator, and OMA. Investigate linearity of beam current vs. light output.
6. Emittance control (increase) by grids.
7. Change gun perveance and look for increased beam current. Transport of higher current through the drift-tubes would require at least partial neutralization.
8. Develop electron beam probe for beam profile measurement.
9. Examine practical schemes for using multiple beams in an induction linac, including matching.

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David L. Judd

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PROCEEDINGS OF THE HEAVY ION FUSION WORKSHOP HELD AT ARGONNE NATIONAL LABORATORY SEPTEMBER 19-26, 1978

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ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

Prepared for the U. S. DEPARTMENT OF ENERGY
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Part III: THE EXPERIMENTAL PROGRAM ON HEAVY ION FUSION AT LAWRENCE BERKELEY LABORATORY*

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(Presented by C. Kim)

1. Introduction

The experimental efforts at LBL have been focused on both the development of a large aperture 2 MeV, 1A Cs^{+1} ion beam[1]) using contact ionization and drift tube techniques as an injector for an induction linac and, also, a 750 kV, 60 mA Xe^{+1} ion beam[2]) using multiaperture accel-decel extraction and a Cockcroft-Walton accelerator high gradient column for an r.f. linac source.

2. The One-Ampere Cesium Source

A schematic diagram of the Cs^{+1} beam experiment is shown in Fig. 1. Neutral Cs atoms, generated either by heating metallic Cs or a (CsCl + Ca) mixture, are sprayed onto a hot iridium plate (anode) of 30 cm dia. which is at a temperature of 1200°K-1400°K. The ionization potential of Cs (3.9V) is smaller than the work function of iridium so that most of the Cs atoms are adsorbed on the anode surface as ions. The supply rate of Cs atoms is determined by the oven temperature and is designed in such a way that there is ~ 1% of a monolayer (1mC) of Cs accumulated on the anode when the extraction voltage pulse is applied to it. The Cs^{+1} ion emission rate is determined by the temperature and coverage of the iridium hot plate and is designed to be about 5 times the space charge limited current. In this space-charge limited operation the beam emission is uniform over the surface independent of the non-uniformities of the temperature of the anode and the neutral Cs flux.

The space-charge limited current is 1A for the extraction voltage of 500 kV which was applied to the anode. Emission-limited operation occured when the anode temperature was below 1100°K in which case the Cs^{+1} current was independent of the applied voltage pulse and depended only upon the anode temperature.

*This work was supported by the Offices of Laser Fusion and of High Energy and Nuclear Physics of the Dept. of Energy.

Cs depletion was observed when the anode temperature was high and the neutral Cs supply was low. In this case all the available Cs ions were used up during the earlier part of the voltage pulse. The space-charge-limited condition was recovered when the oven temperature was increased in this case.

Beam neutralization could increase the current above the classical space charge limit. Our current measurement is not yet accurate enough to establish this because of the undetermined secondary electron correction. Although the secondary electron effect was measured to be small in our earlier Cs test stand experiment, we are building improved diagnostics to delineate the phenomenon.

Time-of-flight measurements, as shown in Figure 2, proved that virtually all of the beam was composed of Cs^{+1} ions. The beam also had orders of magnitude lower intrinsic neutral background pressure compared to any electron-bombardment ionization source. This is as expected since the Saha-Langmuir equation shows that more than 99% of the incident Cs atoms are ionized. The ion beam has a very low thermal velocity equal to the temperature of the anode (0.1 eV). It is thus very bright. Normalized emittance based on the thermal spread is calculated to be $\frac{\varepsilon\beta\gamma}{\pi}$ = 0.006 cm-mrad. The final beam emittance will be determined by non-source-originated mechanisms such as lens aberrations and scattering by grids.

The source is now operating at a few μC capacity but it can be easily scaled up by increasing the extraction voltage (up to 1 MV) and the area of

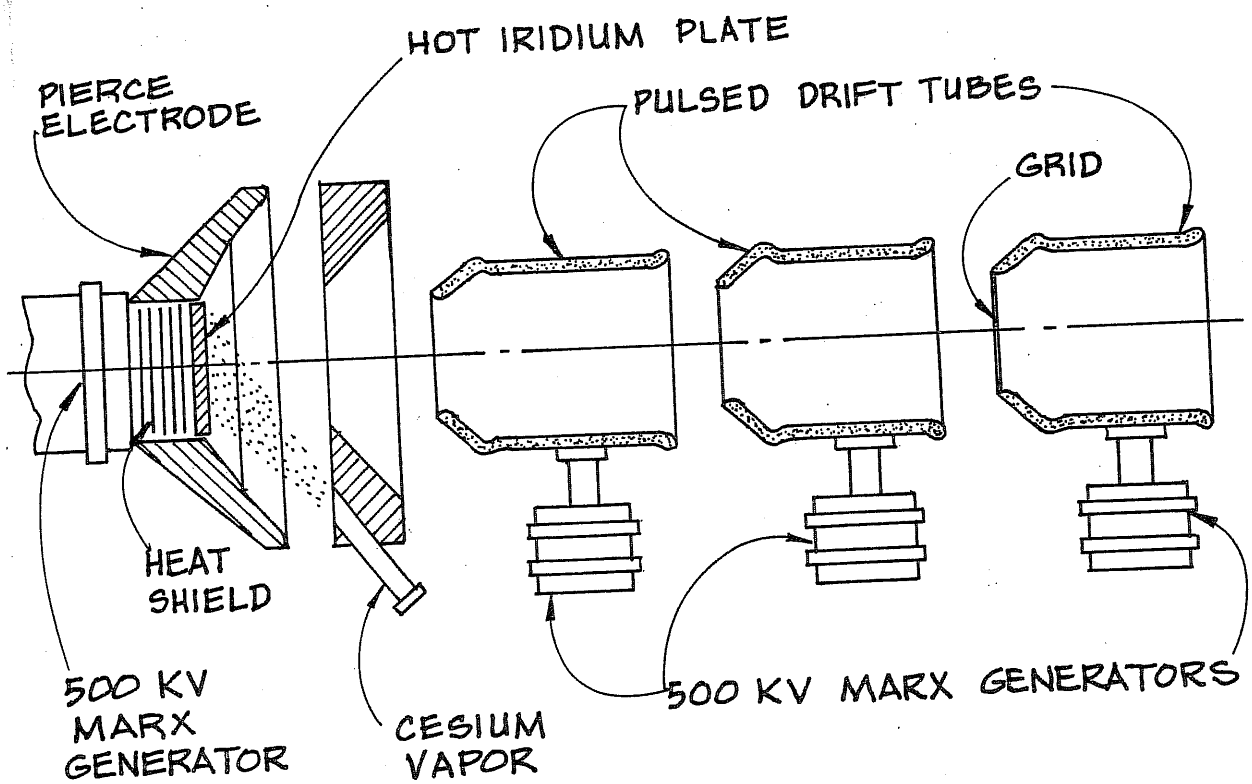

Fig. 1: Schematic diagram of the Cs^{+1} beam experiment
(Drift tube lengths not to scale)

the anode. (The contact ionization source is also applicable to uranium.[4]) Since the uranium ionization potential, approximately 6.3 volts, is higher than the work function of any refractory material, the anode needs to be oxidized or flouridated to obtain a higher work function.) The extracted Cs^{+1} beam is focused by Pierce electrodes[5]) (Fig. 3) and will be further accelerated by a three-section pulsed drift-tube, which is being assembled at the present time. The beam will gain an increment of 500 keV per stage and reach 2 MeV at the end of the drift tubes. Other experiments under consideration are: (1) an addition of accelerating stages using induction linac cavities, and (2) a strong-focusing transport experiment.

Note Added in Proof, January 1979: Since the September workshop, this source has delivered 1.1 amperes of Cs^{+1} ions at 500 kV. In addition, repetition rate tests up to 1 Hz showed reproducible space-charge-limited current pulses.

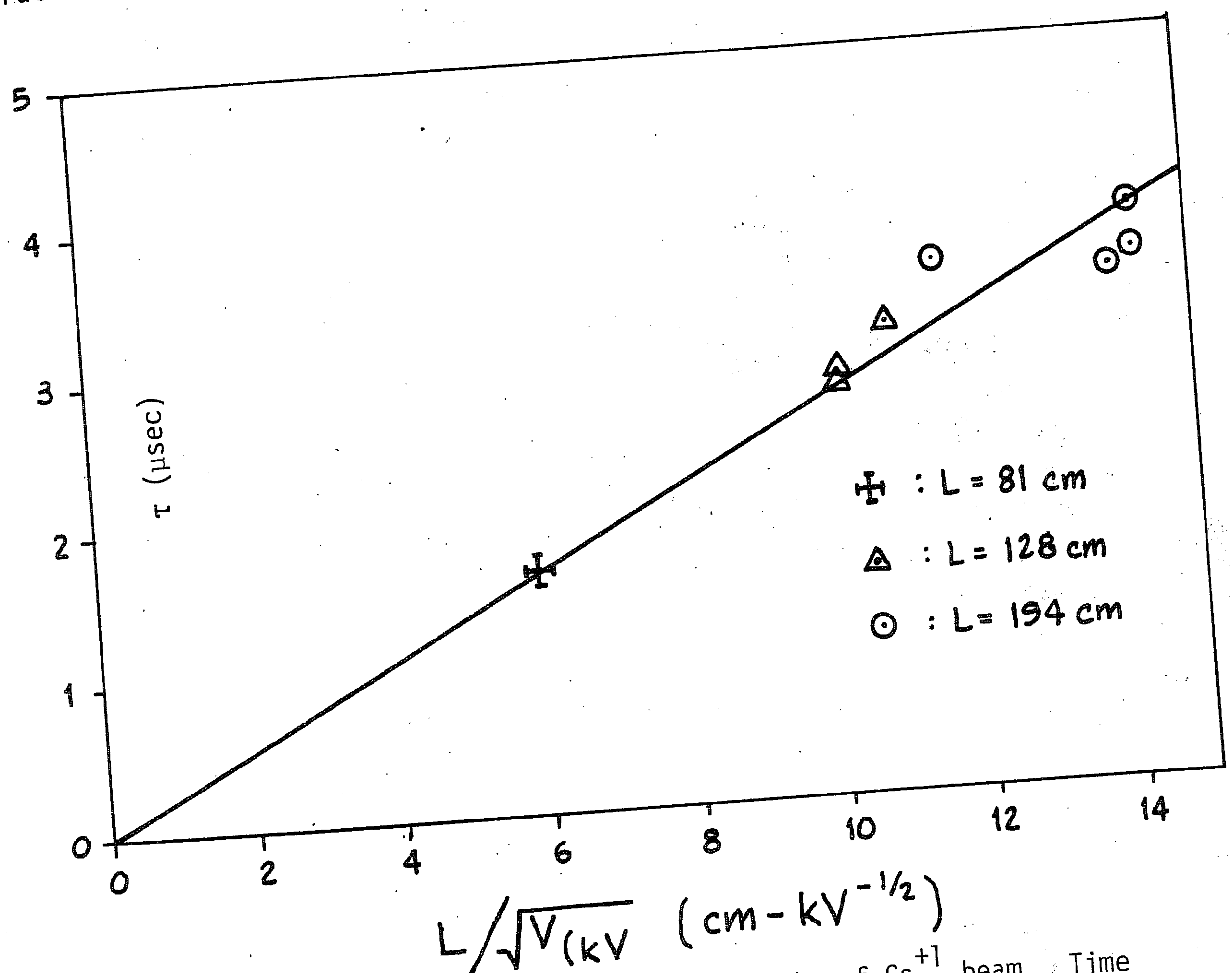

Fig. 2: Time of flight measurements of Cs^{+1} beam. Time was measured from the end of the voltage pulse and the end of the current pulse. Ls are the distances of the drift space.

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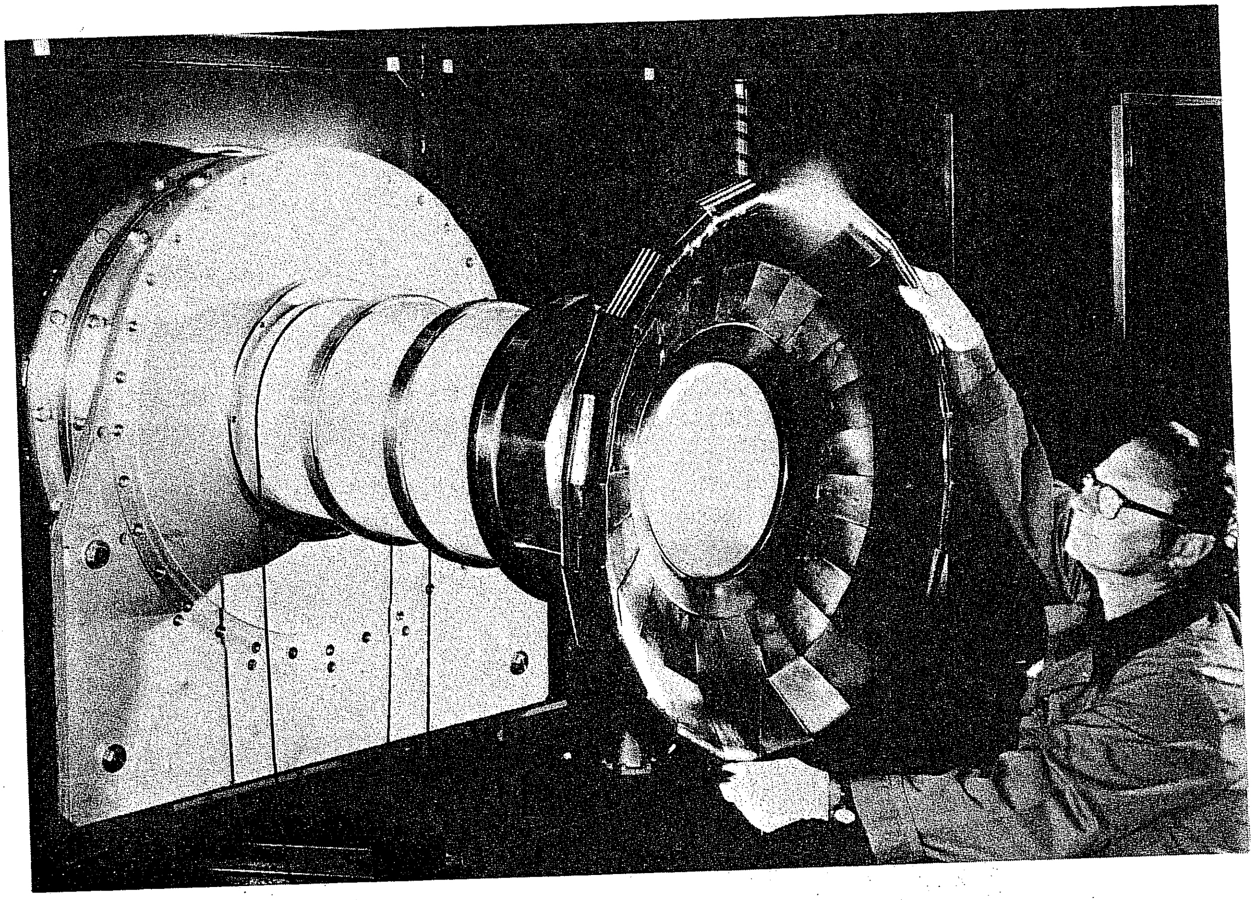


Fig. 3: A photograph showing the iridium hot plate, the Pierce electrode, and insulator column of the Cs^{+1} contact ionization source.

3. The 60 mA Xe^{+1} Source

The Xe^{+1} multiaperture source has been described in Ref. 2. The present source configuration utilizes an array of 13 holes each 4 mm in diameter symmetrically arranged within a 25 mm diameter circle. Development of this source was carried out in the Bevatron 20 kilovolt test stand.

A beam of 40 mA at 20 kV was transported one meter through a quadrupole triplet and measured with a biased Faraday cup. The measured beam diameter was 38 mm and the emittance was $\frac{\varepsilon_n}{\pi} = \frac{\varepsilon\beta\gamma}{\pi} = 0.03$ cm mrad. A 50-degree magnetic analysis showed the beam to contain 90% Xe^{+1} charge state.

This source was then installed in the 750 kilovolt Cockcroft-Walton accelerator. The 20 kV Xe^{+1} beam was transported one meter through two magnetic quadrupole triplets and accelerated to 500 kilovolts through the high gradient column.

A beam of 60 mA was measured with an electrically biased Faraday cup. This cup is also provided with a transverse magnetic field. The observed beam diameter was 38 mm.

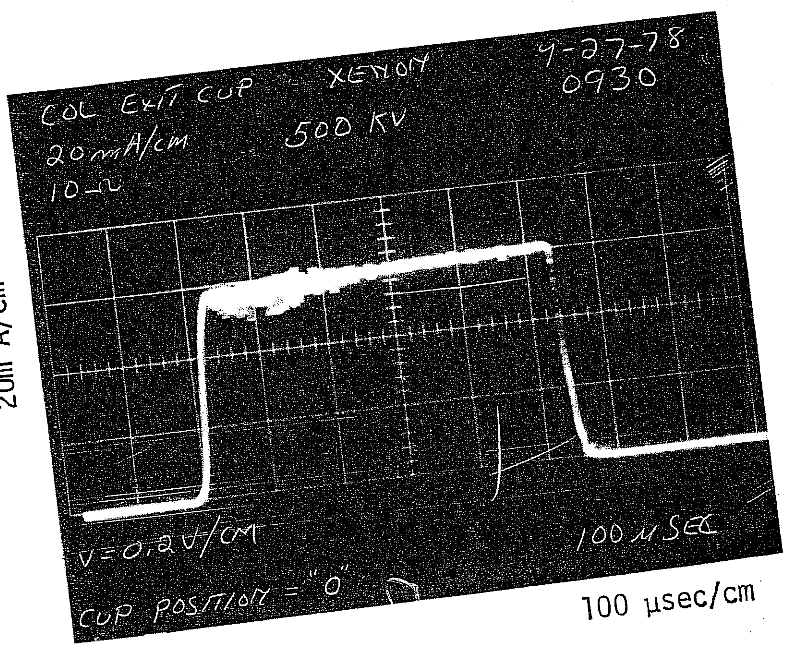
The plasma arc was operated at 30 V and 50 A and a pulse length of 500 µsec. These conditions are the same as on the 20 kilovolt test stand which yielded 90% Xe^{+1}.

A typical beam current pulse is shown in Figure 4.

Our computer calculations show that the two quadrupole triplets can only transport about 1 mA of un-neutralized Xe^{+1}. This implies that the initial beam is more than 98% neutralized.

Measurements of emittance and a magnet analysis of the beam are in progress. Following this the beam energy will be increased to 750 kV.

20m A/cm



100 µsec/cm

Fig. 4: 500 kV Xe^{+1} beam current vs. time

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